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M.L. Meeks

A Propagation Experiment Involving Reflection and Diffraction

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LEXINGTON, MASSACHUSETTS

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MASSACHUSETTS INSTITUTE OF TECHNOLOGY
LINCOLN LABORATORY

A PROPAGATION EXPERIMENT INVOLVING REFLECTION AND DIFFRACTION

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Group 48

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ABSTRACT

Measurements of propagation at a frequency of 1090 MHz over terrain that produces specular reflection and knife-edge diffraction are in good agreement with model calculations that use images to represent the effect of reflection. A hill covered with a pine forest formed the diffracting mask, and an airport area formed the reflecting surface. Agreement between measurements and model calculations required that the diffracting knife-edge be located at treetop level. Optimum propagation into the shadow region was obtained when a maximum in the reflection-lobe pattern coincided with the mask angle.

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1. INTRODUCTION

Our initial measurements investigating radar propagation at low altitudes made use of equipment developed for measurement of the angle of arrival of signals from an aircraft. We designed an experiment using this equipment to study a simple problem that arises in low-angle propagation and that involves both multipath and diffraction: the problem of a knife-edge on a reflecting plane. The equipment allowed us to use a helicopter rather than a tower (which has been used in many other experiments described in the literature) to measure signal strength as a function of height above ground.

Although the problem of radio propagation in the presence of both ground reflection and diffraction over a mask was first analyzed by Schelling, Burrows, and Ferrell[1] in 1933, we have been unable to find satisfactory experimental confirmation of their computational model in the literature. Notwithstanding the simplified computational method of Anderson, Trolese, and Weisbrod,[2] the numerical solution to the modeling problem was tedious without a digital computer, and solutions for only a few cases have been published. We have programmed exact solutions for the Schelling, Burrows, and Ferrell model.[1] We present here a comparison of model predictions and experimental results for propagation at an L-band frequency over a hilltop with ground reflections occurring on one side of the mask. The helicopter allowed us to probe the propagated wave as the aircraft descended vertically from the illuminated region into the shadow region.

2. THE PROPAGATION MODEL

The familiar problem of propagation over a reflecting plane surface is solved by introducing the virtual image of the transmitter (or receiver) and considering the propagated waves from transmitter to receiver and from transmitter to receiver-image (or equivalently from transmitter-image to receiver). Similarly, the problem of propagation over a plane surface with a knife-edge barrier is solved by including the ray paths between transmitter and receiver and their respective images. Schelling, Burrows, and Ferrell[1] show that in the general case one must consider four rays. A detailed formulation of this problem is given by Anderson, Trolese, and Weisbrod.[2] In their formulation one can assign reflection coefficients independently to the ground in front of and behind the knife-edge. If either of these surfaces is nonreflective, then only two rays need to be taken into account. We have prepared a computer program to calculate the general solution to the four-ray problem; a more complete discussion of the solution and Fortran listing of the program are given by Meeks.[3] The exact form of the Fresnel integral is used in these computations.

To illustrate the characteristics of this propagation model we consider a case in which the geometrical arrangement is typical of that encountered in our propagation measurements. The propagation path extends from a helicopter making a vertical descent to a fixed antenna on the ground. The distance between transmitter and receiver is 3.5 km; the knife-edge has a height of 41 m and is 900 m from the ground-based antenna; the height of the fixed antenna is 6.5 m; the radio frequency is 1090 MHz; and the polarization is vertical linear. Figure 1 shows computed values of the received signal in decibels relative to free-space propagation plotted as a function of helicopter height above ground. Figure 1(a) shows the case in which we have flat, reflecting ground (relative dielectric constant 15 and conductivity 0.005 mho/m) between the ground-based antenna and the knife-edge and nonreflecting terrain beyond the knife-edge. The lowest line of sight over the mask is indicated by the arrow labeled LOS. Note that in Fig. 1(a) the signal below the mask decreases monotonically due to diffraction, and the signal above the mask shows the expected reflection-lobe pattern modulated by ripples characteristic of knife-edge diffraction. In Fig. 1(b) the terrain between the ground-based antenna and the mask is taken as nonreflecting, and the terrain beyond the mask is assumed to be flat, with a reflection coefficient determined by the above material parameters. In this case we obtain

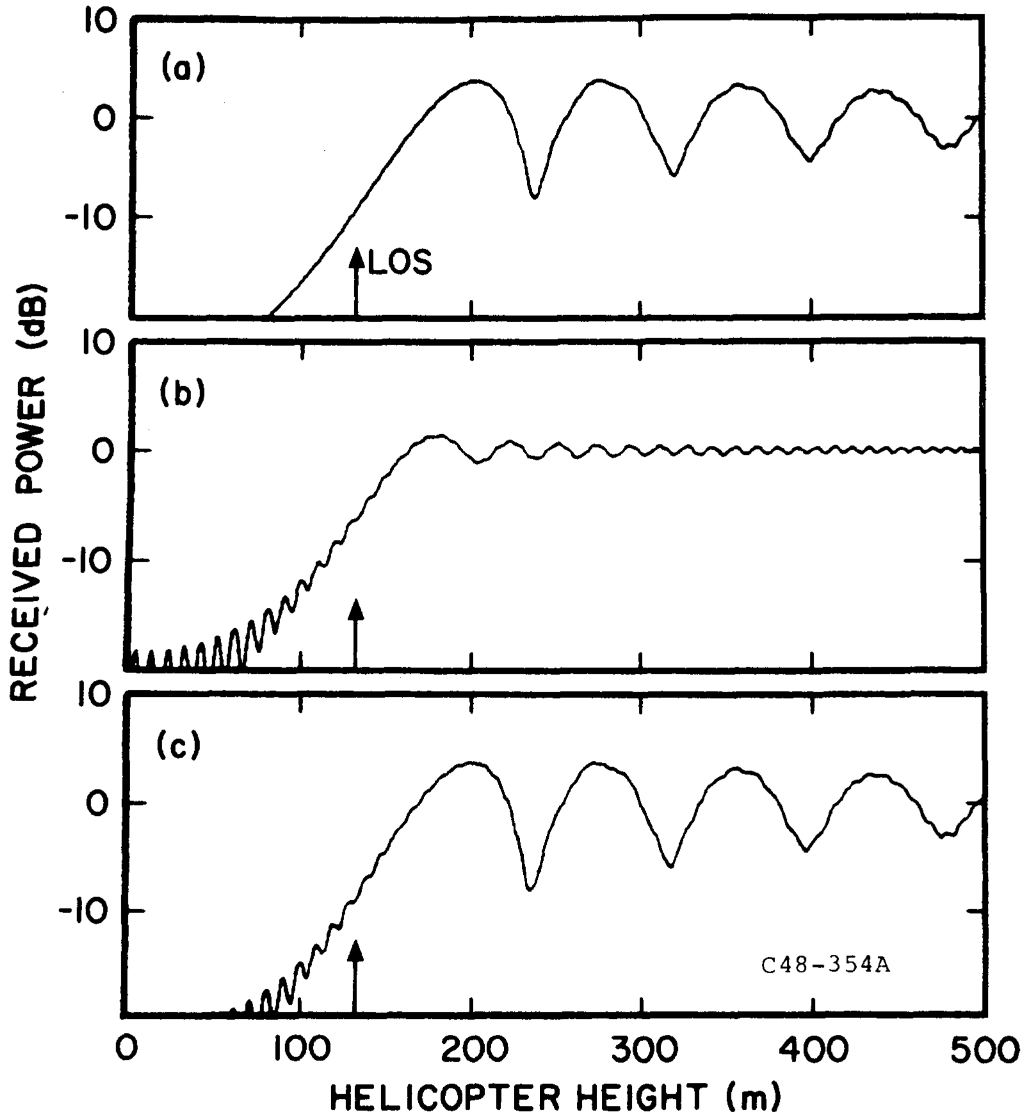

Fig. 1. Model calculations of propagation over a knife-edge on a reflecting plane. (a) Ground reflections occur only between the ground-based antenna and the mask. (b) Ground reflections occur only between the mask and the helicopter, and (c) ground reflections occur on both sides of the mask. The helicopter height at the shadow boundary is labeled LOS.

the Fresnel diffraction pattern above the mask; below the mask a lobe pattern modulates the signal in the shadow region. The lobing results because the knife-edge acts as a source located at the diffracting edge. This is the so-called edge wave described in Rice.[4] In Fig. 1(c) reflections are assumed from the ground on both sides of the mask. The measurements described in Sec. 3 correspond to the cases shown in Figs. 1(a) and 1(b).

3. THE PROPAGATION MEASUREMENTS

We made propagation measurements in February 1979 near Hanscom Field in Bedford, Massachusetts, at a radio frequency of 1090 MHz. The propagation path extended from ground-based antennas on the airfield to a helicopter at a distance of 3.5 km. Measurements were made as the helicopter descended vertically from an altitude of 550 m above ground. Figure 2 shows the geometrical arrangement. The propagation path extended over the flat western part of Hanscom Field and across the top of Pine Hill at a range of 900 m from the ground-based antennas. Pine Hill formed a diffracting mask beyond the flat grassy surface of the airport. Figure 3 shows the view from the ground antenna looking toward Pine Hill. The ground at hilltop level is 32 m above the airport and is covered with a pine forest, average tree height 9 m. Figure 4 shows an aerial view of the ground-antenna location, Pine Hill, and the terrain on the other

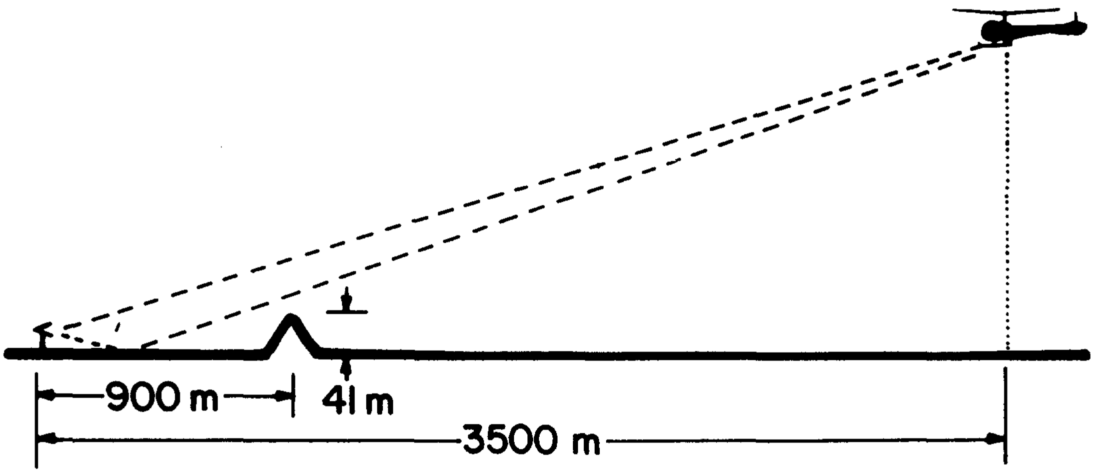

Fig. 2. Geometry of the propagation path.

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Fig. 3. Pine Hill viewed from the ground-antenna tower.

Fig. 4. Aerial view showing the propagation path.

side of Pine Hill. The terrain beyond Pine Hill is generally flat but forested, so negligible specular terrain reflection would be expected on the helicopter side of the mask.

The propagation measurements were made with an existing system which is somewhat more elaborate than our experiment required. The system is described by Evans.[5] For the measurements reported here, the transponder was carried in a helicopter, and the received power was measured independently at eleven vertically polarized dipole-antennas mounted at various heights on an 8-m tower. Dipoles numbered 1 through 9 were spaced 0.8925 m apart on the tower, with dipole 1 at a height of 0.91 m above ground. Two additional dipoles, designated 2.5 and 3.5, were located halfway between dipoles 2 and 3 and dipoles 3 and 4, respectively. All measurements were made during a single helicopter descent. The signal received on each dipole was recorded separately in digital format so the data could be processed by computer immediately following the experiment. When the helicopter was well above the mask, diffraction was insignificant, and specular reflection occurred from the flat terrain in front of Pine Hill. Hence, the modeling problem reduced to that of propagation over a reflecting plane, as confirmed by Fig. 1(a). The signal measured on each antenna was calibrated relative to free-space propagation by fitting data taken well above the mask to the predictions of this simple model.

The received power was measured with a Singermetrics 37/57 EMI field intensity meter and recorded on a decibel scale with a Hewlett-Packard 7155B chart recorder. The altitude indicated by the helicopter's barometric altimeter was recorded as a function of time on a cassette audio recorder, and the recording was synchronized with the chart record. In this way, we obtained a record of signal strength as a function of height. The descent rate was roughly 5 m/sec. Taking into account errors in timing and altitude, we estimate that the resulting height errors in the signal strength data are less than 10 m in altitude.

4. ANALYSIS OF THE EXPERIMENTAL RESULTS

Transponder signals from the helicopter, normalized to free-space propagation, are plotted as of function of elevation angle in Fig. 5. The measured data received at each of the eleven dipoles antennas are plotted as points in this figure, and the corresponding model predictions are plotted as smooth curves. Generally, the agreement between measurements and predictions is very good, with the lobes and nulls appearing at the predicted elevation angles. However, for dipoles 2 through 6 we note that some of the nulls are much deeper than the model predicts, indicating that the amplitude of the reflected wave is significantly stronger than predicted on the basis of the Fresnel reflection coefficient

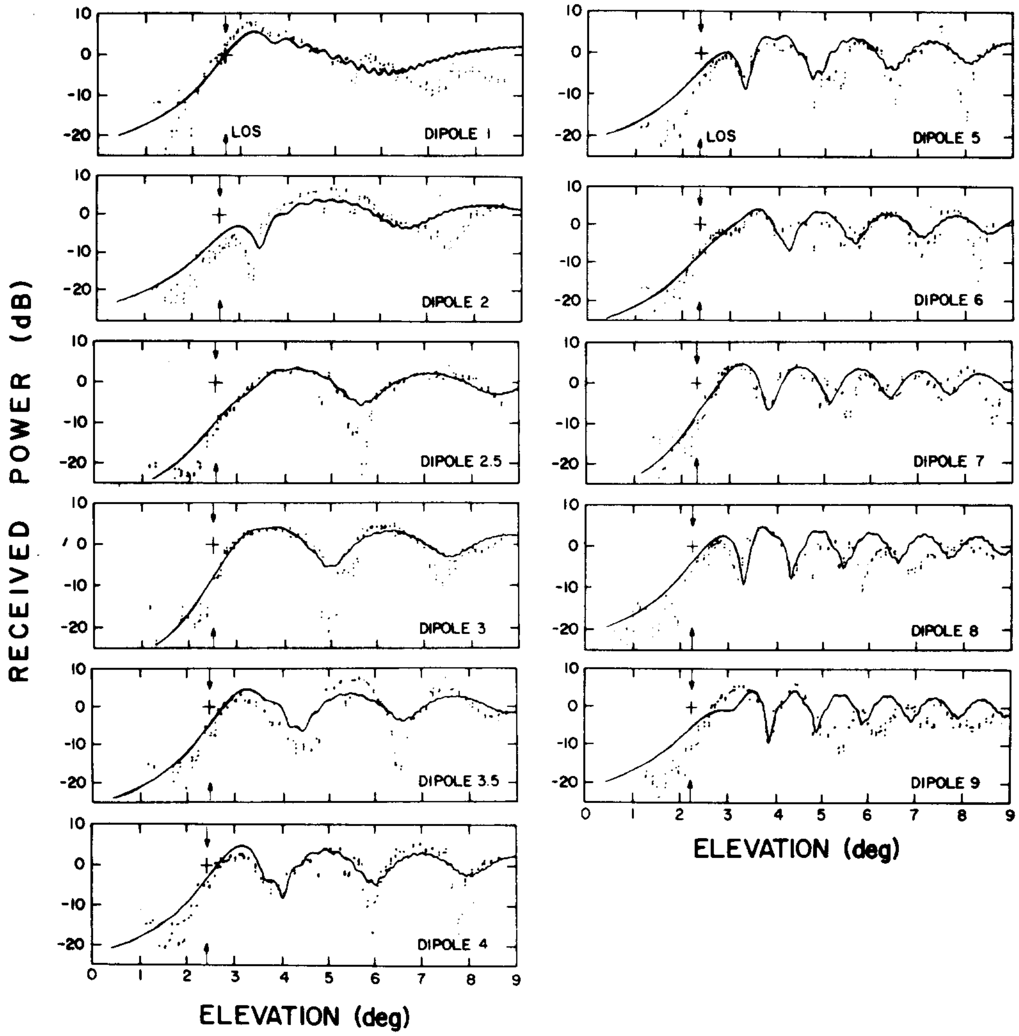

Fig. 5. The received power measured and calculated for the ground-based antennas as a function of helicopter elevation-angle. Curves represent the model calculations, and points represent the measurements. A cross corresponding to free-space propagation at the mask angle (LOS) is plotted on each graph.

for dry ground and vertical polarization. To explain this discrepancy, we examined the profile of the flat terrain along the propagation path. This profile is shown in Fig. 6. Note that a concave depression with a depth of 0.4 m lying within the first 100 m in front of the antenna tower. For dipole 4 at an elevation angle of 6 degrees the first Fresnel zone on the ground coincides with this depression, as indicated in Fig. 6, and the deeper null appears in the data at this elevation. This suggests that the terrain profile produced focusing action on the reflected wave. If so, we would expect enhanced reflection from this concave area at lower elevation angles for antennas below dipole 4 and at higher angles for antennas above dipole 4. The data in Fig. 2 do show this behavior.

The elevation angle representing the lowest line of sight over the mask (slightly different for each dipole) is indicated in Fig. 5 by arrows labeled LOS. These angles correspond to the tops of trees on Pine Hill, not the top of the hill itself; the agreement between model and the data is unsatisfactory unless the trees are included in establishing the height of the diffraction mask. Below the mask the agreement between data and model is less good, as Fig. 5 shows, and the measured signal strength is generally weaker than predicted and more variable. This is probably a result of gain variation in the helicopter antenna pattern when the aircraft turned near the ground.

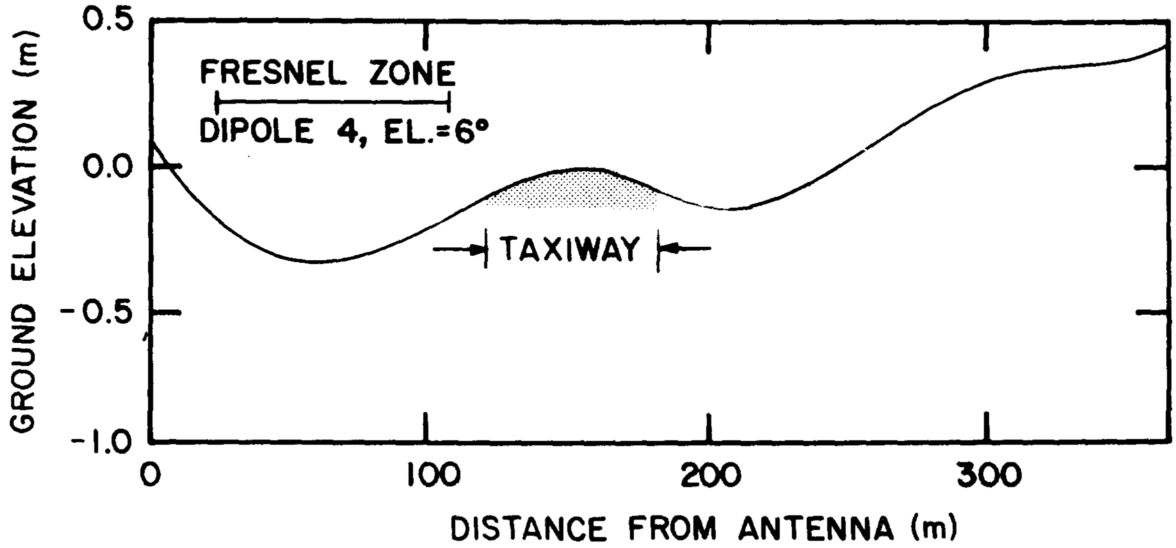

Fig. 6. Terrain profile in front of the ground-based antennas. The extent of the first Fresnel zone for dipole 4 is shown for an elevation angle of 6 degrees.

If there were no ground reflection we would expect a propagation loss of 6 dB at the elevation angle of the knife-edge. However, Fig. 5 shows that this is not the case in the presence of ground reflection. As a reference point, a cross is plotted in Fig. 5 at points corresponding to no loss at the mask angle. For dipole 1, the lowest antenna, we find no loss at the mask angle; on the other hand, for the dipole 2.5 the loss is 9 dB at the mask angle. To explain this behavior, we examine the model predictions when holding the elevation angle of the helicopter fixed and varying the height of the receiving antenna. In other words, we vary the height over reflecting ground rather than over nonreflecting ground. Figure 7 shows model predictions for three different helicopter altitudes: 130, 160, and 200 m. At the 200-m altitude the helicopter is above the mask for all the dipole antennas; at the 130-m altitude the elevation angle is 2.1 degrees, below the mask for all dipole antennas, as Fig. 5 indicates. Heights of all the dipoles are indicated in Fig. 7, and we note that dipole 1 is located near a maximum in the propagation pattern, while dipole 2.5 is located near a minimum. Comparing Fig. 5 with Fig. 7 for other dipoles, we see that the performance of dipoles near the mask angle can be understood in terms of the calculations shown in Fig. 7.

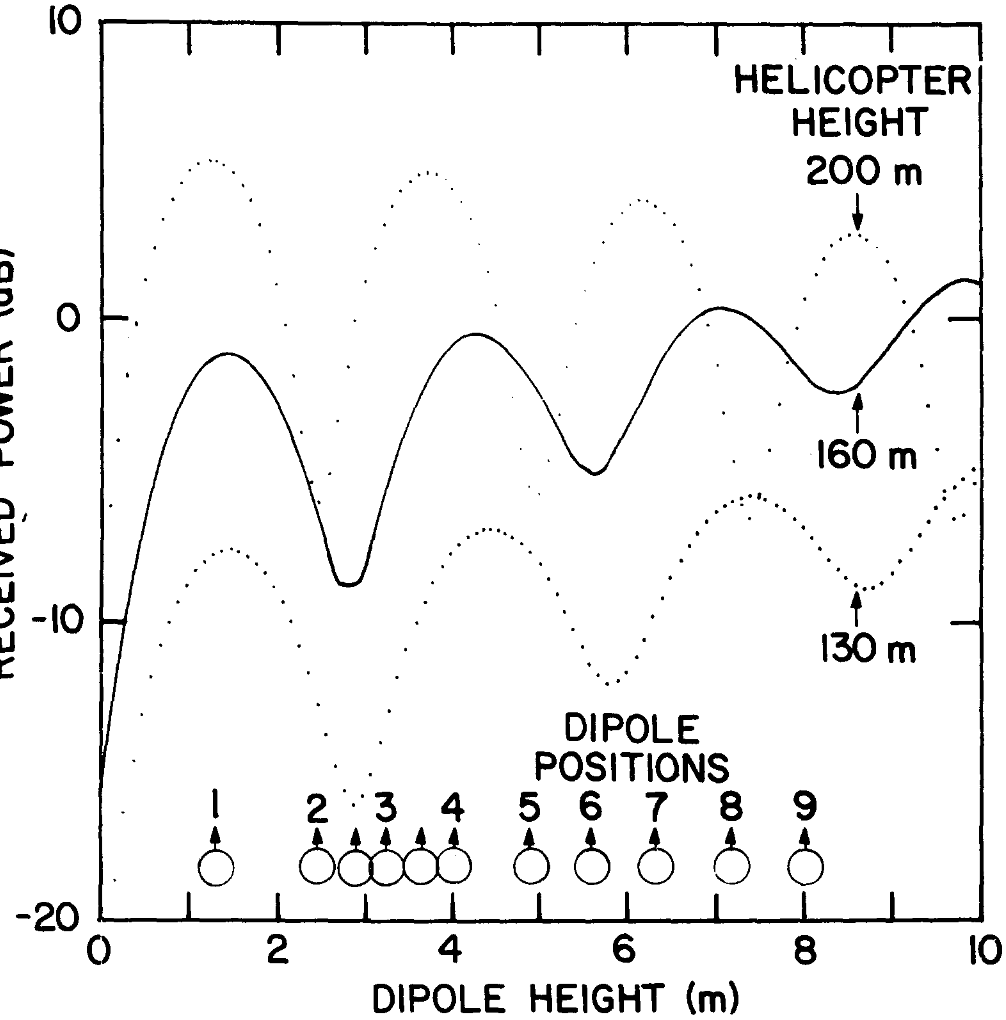

Fig. 7. Model calculations of received power as a function of ground-antenna height for three helicopter heights. The heights of the dipole antennas are indicated.

5. CONCLUSIONS

The combined effects of diffraction by a knife-edge and reflection from a plane surface have been modeled by introducing appropriate images of the transmitter and receiver. Our measurements in which ground reflection occurs on one side of a mask confirm these model predictions. At a frequency of 1090 MHz we found that a hill covered with a pine forest acts as a knife-edge, with the diffracting edge at treetop level. We also found in the shadow region that the diffracted edge-wave acts as a secondary source; maximum power is propagated near and below the shadow boundary when a reflection-lobe maximum occurs at the masking angle. In our measurements the helicopter proved to be a useful tool for probing the field propagated at low altitudes.

ACKNOWLEDGMENTS

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REFERENCES

1. J.C. Schelling, C.R. Burrows, and E.B. Ferrell, Proc. IRE, 21, 427-463 (1933).
2. L.J. Anderson, L.G. Trolese, and S. Weisbrod, "Simplified Method for Computing Knife-edge Diffraction in the Shadow Region," in Electromagnetic Wave Propagation, M. Desirant and J. Michiels, eds. (Academic Press, New York, 1960).
3. M.L. Meeks, "Radar Propagation at Low Altitudes: A Review and Bibliography," Technical Report TR-580, Lincoln Laboratory, M.I.T. (August 1981).
4. S.O. Rice, Bell Sys. Tech. J., 33, 417-504 (1954).
5. J.E. Evans, IEEE Trans. Antennas Propag. AES-15, 891-895 (1979).

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Measurements of propagation at a frequency of 1090 MHz over terrain that produces specular reflection and knife-edge diffraction are in good agreement with model calculations that use images to represent the effect of reflection. A hill covered with a pine forest formed the diffracting mask, and an airport area formed the reflecting surface. Agreement between measurements and model calculations required that the diffracting knife-edge be located at treetop level. Optimum propagation into the shadow region was obtained when a maximum in the reflection-lobe pattern coincided with the mask angle.

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